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Coarse root topology of Norway spruce (*Picea abies*) and its effects on slope stability

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The structural distribution of coarse roots and its beneficial effects on soil reinforcement has widely been assessed. However, it is still not fully understood how topological features of coarse roots (e.g. branching patterns) are affected by slope inclination and further influence the ability of young trees to reinforce soil. This study aims to analyse empirically the impact of slope gradient on the topological development of coarse roots and thus to assess its effects on soil reinforcement. We performed root system excavations on two young *Picea abies*: tree A on a gently inclined plane ($\beta \approx 12°$) where slope failures are not expected; tree B on a slope ($\beta \approx 35°$) with failure potential. The diameter (d) of the segments between distinct root nodes (root ends, branching locations, direction changes and attachments to stem) of coarse roots ($d > 2mm$) were measured in situ. The spatial coordinates (x, y, z) of the nodes and surface were measured on a plane raster grid, from which segment length (l_s), direction and inclination towards the surface (β_r) were derived. Roots and segments were classified into laterals ($\beta_r < 10°$), obliques ($10° \leq \beta_r < 70°$) and verticals ($\beta_r \geq 70°$), with $\beta_{r,max} = 90°$. We assigned topological orders to the segments according to developmental (DSC) and functional segment classifications (FSC), to obtain quantitative relations between the topological order and number of segments, total and average l_s. The maximal root cohesion (c_r) of each segment was assessed using material specific tensile forces (T_r), root area ratio (RAR) and β_r, assuming that a potential slip surface would cross the root system parallel to the slope. Laterals depicted the majority of roots (57 %) for tree A orientated rather in upslope direction (76.8 %), whereas tree B showed mostly obliques (54 %) orientated rather in downslope direction (55.4 %). Vertical roots were scarcely observable for both trees. DSC showed a high r^2 (> 0.84) for the segments and l_s. FSC showed high r^2 (> 0.95) for the number of segments and the total length. RAR values of tree B are distributed rather upslope (76.8 % of RAR_{tot}), compared to 44.5 % of RAR_{tot} for tree A. The average c_r (0.15) of each segment of tree B was remarkably higher than of tree A (0.10), leading to the conclusion that the slope has a strong influence on c_r itself. This is supported by comparing the distribution of c_r for both trees, where tree B tends to produce a higher c_r in upslope direction (68.7 % of total c_r) than tree A (37.7 %). In contrast to our expectations, tree B shows generally a higher c_r compared to tree A, despite lower subsurface biomass. The findings indicate that the distinct branching patterns of coarse roots might determine the distribution of the RAR and thus lead to a higher reinforcement potential of young *Picea abies* on slopes.